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NUCLEAR GAMMA RAYS AND
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The Identification of Optical Continuum Emission with the Phase of Electron Acceleration in Solar Flares

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For seven white light flares (WLFs) we compare photometric optical measurements with hard x–ray data from ISEE–3 and SMM/HXRBS and soft x–ray data from GOES, and obtain the following results: (1) in six cases there is good temporal correlation between $\gtrsim 50$ keV hard x–rays and power radiated in optical continuum, (2) there is poor temporal correlation between 1–8 Å soft x–rays and power radiated in optical continuum, with the latter peaking 1 to 2 min earlier than the soft x–rays in six cases, (3) in all cases the electron energy E_*, above which the power in nonthermal electrons is equal to the power in optical continuum, is $\gtrsim 50$ keV at the peak of the WLF, although during the WLF decay E_* shifts to lower energy (typically $\gtrsim 25$ keV), and (4) the power in 1–8 Å soft x–rays is approximately one order of magnitude less than the power in optical continuum at the peak of the WLF. We therefore conclude that the majority of the WLF emission cannot be produced via irradiation by soft x–rays and that, in general, the WLF is associated with the phase of electron acceleration in the flare, rather than with the thermal phase. We further point out that the optical continuum may show both an impulsive and a gradual component, but in any case it tends to track the hard x–ray emission.

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SOLAR FLARE NUCLEAR GAMMA-RAYS AND INTERPLANETARY PROTON EVENTS

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ABSTRACT

We have compared separately compiled lists of solar flare nuclear γ-ray line (GRL) events and solar energetic proton (SEP) events for the period from 1980 February to 1985 January. The GRL data are from the gamma-ray spectrometer on the *Solar Maximum Mission* (*SMM*) satellite. For SEP parent flares not observed by *SMM*, we inferred GRL fluences, or upper limits, from correlations between the 4–8 MeV GRL fluence and other (>300 keV X-ray, 9 GHz microwave) flare emissions. As our principal result, we find a lack of correlation between flare 4–8 MeV GRL fluences and the peak fluxes of ~10 MeV protons in interplanetary space. This poor correlation is primarily due to several large SEP events that originated in flares without detected (or inferred) GRL emission. The converse case of GRL flares unassociated with SEP events is rare. The ratio (R) of the number of ~10 MeV protons that produce GRL emission at the flare site to the number of ~10 MeV protons detected in space can vary from event to event by 4 orders of magnitude. There is a clear tendency for impulsive flares to have larger values of R than long-duration flares, where the flare time scale is given by the e-folding decay time of the associated soft X-ray emission. We discuss these findings in terms of other recent work on particle acceleration in solar flares.

Subject headings: gamma-rays: general — particle acceleration — Sun: flares

I. INTRODUCTION

The acceleration of protons to high energies during solar flares has been of interest since the first report, over four decades ago, of a solar "cosmic-ray" event at Earth (Forbush 1946). Much of what we know about proton acceleration (see Ramaty *et al.* 1980; Vlahos *et al.* 1986; Lin 1987; and Ramaty and Murphy 1987 for recent reviews) has come from the study of solar energetic particles in space. Until the launch of the *Solar Maximum Mission* (*SMM*) satellite in 1980, any additional information on the acceleration of nuclei had to be inferred, with few exceptions (Chupp, Forrest, and Suri 1975; Hudson *et al.* 1980; Chambon *et al.* 1981; and Prince *et al.* 1982), from the electromagnetic emissions of flare-energized electrons. To date, the gamma-ray spectrometer (GRS) on *SMM* has observed the γ-ray line emission due to protons interacting in the solar atmosphere from ~50 flares. This makes it possible to compare statistically the properties of solar energetic protons observed in space with those of the proton population at the flare site.

The earliest such comparisons using these new data yielded a surprising lack of correspondence between flare nuclear γ-ray line fluences and the sizes of interplanetary proton events. However, these early reports were based for the most part on a relatively small sample of events observed mainly in 1980–1981 (von Rosenvinge, Ramaty, and Reames 1981 [two events]; Pesses *et al.* 1981 [<10 events]; and Cliver *et al.* 1983*a* [16 events]) (see also Chambon *et al.* 1981; Yoshimori and Watanabe 1985). More recently, preliminary reports have been given for two studies on extended data sets (Cliver *et al.* 1987*a* [48 events] and Kallenrode *et al.* 1987 [24 events]). This paper is an expanded version of our preliminary (Cliver *et al.* 1987*a*) report. In it, we compare γ-ray line (GRL) and solar energetic proton (SEP) events observed from 1980 February through 1985 January in order to substantiate and better characterize the lack of correlation between GRL fluences and SEP event peak fluxes. For example, we will show that while even large SEP events can originate in flares lacking detectable GRL emission, the converse case of flares with a significant GRL line fluence but lacking protons in space is rare.

A second focus of this paper is the finding by Cane, McGuire, and von Rosenvinge (1986) and Bai (1986) (see Kocharov, Kovaltsov, and Kocharov 1983) that the characteristic time scale of the flare X-ray emission (hard or soft) is an important parameter that can "order" the γ-ray/proton observations. In particular, for a sample of 10 GRL/SEP flares, Bai (1986) showed that the ratio of the number of γ-ray producing protons to the number of interplanetary protons varies greatly from event to event but that, on average, this ratio is higher for impulsive flares than for gradual flares. In the present study, we examine how this ratio varies with flare scale time for the 1980–1985 GRL/SEP data set.

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